Electron Beam Irradiated Polymeric Materials for Opto-Electronics Devices Applications

Final Synopsis submitting in fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

In

P H Y S I C S

By

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SYNOPSIS

Polymer electrolytes are electrolytic materials has created an interest of researchers and industries due to their alternative material for electrochemical energy storage device applications such as lithium rechargeable batteries, fuel cells, electrochemical, electro chromic devices, sensors, and super capacitors. Polymer electrolytes are new category solid electrolytes prominent material for potential applications in the development of various electrochemical devices in the last three decades because they possess high electrical conductivity (~10^{-5} to ~10^{-3} S/cm) compared to the existing liquid electrolytes and having solid free standing consistency. In recent days the polymers are play a very important role in the developing of advancement in the science and technology as well as industrial applications such as solid state batteries, fuel cells, sensors, opto-electronics and electro chromic windows. In addition, it is acting as a medium for ion transport medium between the active components of the device. Despite the practical importance of these materials in potential applications could be the reason for researchers to divert their curiosity to study the physical property polymeric materials. These materials are having the scope for tuning their physical properties as per requirement using simple methods by dopant, composite, blending and providing the direct energy to the system via irradiation etc. The solid polymer electrolytes (SPEs) are the key materials for different optoelectronic, electrochemical devices, such as rechargeable batteries, electro chromic displays, super capacitors, solar cells etc. To reduce costs and enhance the lifetime of a device, it is necessary to obtain SPEs with good stability in electrochemical mechanism under the applied voltage at room temperature. To achieve the stable and efficient material; it is necessary to make out the good charge transport materials at the room temperature thereafter, researchers rushed towards polymer electrolytes.

Recently, these materials show more substantial modification in physical properties subject to various irradiation processes like electron beam irradiation, gamma irradiation, X-ray irradiation, UV, proton, and ion irradiation etc.

Electron Beam (EB) radiation is a most suitable one among the all radiation because it directly energy supplied to material. Whenever radiation interacts with the material, it may undergo the radiation processing cause the material degradation or modification in terms of chain scission and cross linking processes as a result the formation of fragments, free radicals, breaking of bonds, evolution of H-bond appearance of carbonyl bonds, formation of bonding, and change the molecular weight. These variations in the material are responsible for molecular rearrangement of polymer matrix causes the improvements in the electrical, optical, and thermal properties.

The main effect of radiation on polymers is the produce of ionization and excitation. Subsequently rupture of chemical bond yields the polymer chain fragments, which may hold unpaired electrons from the broken bonds as a result formation of free radicals it may responsible to change the physio-chemical properties of the polymers. There are various major processes undergoes whenever ionizing radiation interact with polymeric materials as followed;

Cross-linking- is the process in which polymer chains are joined and forms three dimensional network.

Long chain branching- is a process in which polymer chains are joined but the network is not yet formed.

Chain scission- results the reduction of molecular weight of polymer, caused most frequently by oxidation or other form of degradation.

Polymerization- is initiated by the irradiation of the monomer and/or oligomers. The combination of polymerization and cross-linking is referred to as radiation curing.

Grafting- is a chemical reaction proceeding by polymerization of a new monomer and attachment of new chains to the main chain of the base polymer.

The irradiation of polymeric materials with ionizing electron beam radiation leads to the formation of very reactive intermediates, free radicals, ions and excited states. These intermediates can follow several reaction paths that the result in disproportion, hydrogen abstraction, arrangements and/or the formation of new bonds. The degree of these transformations depends on the structure of the polymer and the conditions of treatment before and after irradiation. The proper control of all of these factors facilitates the modification of polymers by radiation processing. The radiation not only alters the chemical structure of the polymer, but it can also enhance the presence of trapped charges or creates defects in the polymer matrix. Thus, these alterations are responsible for the change in the dielectric, electrical and thermal properties of irradiated polymers. The radiation effect on the physical and structural properties of polymeric material are required to study particularly, when such devices are being used in radiation environment. Thus, it is necessary to understand the influence of EB radiation on the physical properties of polymer electrolytes for exploiting their potential applications.

The present study focused on the opt-electronic device applications of polymer electrolytes being irradiated with electron beam (EB) radiation. This work is mainly aimed to study the modifications in the polymer electrolytes due to irradiation at different doses. The main aims and objective of this research work were proposed as following.

The aims and objective of present work are as follow;

- Preparation of doped polymer electrolyte films using solution casting method.
- Prepared polymer samples are exposed to Electron Beam irradiation.
- The unirradiated and irradiated films are characterized by Fourier Transform Infrared (FTIR), X-ray diffraction (XRD), Differential Scanning Calorimeter (DSC), Scanning Electron Microscope (SEM) to know chemical interaction, thermal studies, morphology and structural phase. Dielectric and ac conductivity studies were carried out by LCR6500B impedance analyzer.
- Opto-electronic properties are studied with the help of Current- Voltage (I-V) characteristics.

The polymer samples have been prepared and the irradiated with 8 MeV electron beam radiation energy at 40, 80, and 120 kGy dosage. After irradiation the study and characterizations have done according to the aims and objects as proposed. Finally we achieved the expectations of the proposed work.

The scope of the research work presented in this thesis focused on the EB radiation effects on the properties of polymer electrolytes. The significant changes in the properties of the polymer electrolytes due to irradiation will definitely help to deserve its candidature for various applications. The thesis was distributed chapter-wise and presented in six chapters as following,

The present work is categorized into the following chapters:

Chapter- 1

This chapter concerns introduction to the fundamentals of polymers, polymer electrolytes, and classification and physical properties. The importance of the irradiation techniques, mainly electron beam irradiation influence on polymers. The effects of irradiation on physical and

chemical properties of polymer electrolytes are explained. Literature review of previous reported results on physical properties of polymer electrolytes and electron beam irradiated polymer electrolytes. The motivation to initiation the aims and objective of this study was elaborated in brief.

Chapter- 2

This chapter gives the brief about polymers used, dopants and chemicals such as Poly (vinylidene fluoride-co-hexafluoropropylene), Poly (ethylene oxide), and polyaniline, Lithium perchlorate, copper oxide nano particles and dimethyl formamide used as solvent. The electron beam irradiation was done as 40, 80 and 120 kGy dosage. Followed by the experimental methods and characterization techniques have been employed.

Chapter- 3

This chapter describes the effect of 8MeV of electron beam (EB) irradiation on the optical properties, electrical conductivity and dielectric properties of lithium perchlorate (LiClO4) doped Poly (vinylidene fluoride-co-hexafluoropropylene) (PVDF-FHP) film. The structural and chemical characterizations were studied using Fourier Transform Infrared (FTIR) and X-ray diffractometer (XRD) techniques respectively before and after irradiation. The morphology study carried out using Scanning Electronic Microscopy (SEM) and atomic microscopic analysis. Thermal and optical studies were carried out using the thermal techniques (TGA, DTA, DSC), and UV-Visible spectroscopy, fluorescence analysis respectively. The real (ε') and imaginary (ε'') part of the dielectric parameters suddenly found decreased in a low frequency region (40-640Hz), subsequently independent at higher frequency. The AC conductivity

showed increases with frequency and temperature for all films. The D C electrical conductivity showed increases with dose and temperature. The maximum conductivity of $1.1x10^{-3}$ S/cm, dielectric constant and AC conductivity observed increases with increasing the EB dosage 40, 80 and 120 kGy. The electrochemical study was show improved after the irradiation.

Chapter - 4

This chapter describes the effect of electron beam irradiation on PVDF-HFP/PEO polymer blend electrolyte films. The change in the structure, morphology, crystallinity, dielectric constant, and AC conductivity with dose were studied. The chemical change after irradiation was confirmed from the FT-IR results. The DSC result showed that the decrease in melting temperature with dose suggesting an exothermic behavior. The SEM images show that the size of spherulite found decrease with increasing dose. The XRD result reveals a decreased crystallite size for 120kGy dose compared with unirradiated film. Further, it is seen that dielectric permittivity and frequency dependent conductivity were found to be increases with increasing the irradiation dose. The good thermal stability and decreased percentage of crystallization by the irradiation is confirmed after irradiation. The dielectric parameters and conductivities of the polymer blend were enhanced after EB irradiation and electrical conductivity increased three orders of magnitude and it represents stable electrochemical behaviour at different scan rates.

Chapter- 5

Polyaniline/$LiClO_4$/CuO (PLC) composite was prepared by simple chemical polymerization method and subjected to electron beam (EB) irradiation at various dosages. The characterization

of PLC composite was done before and after EB irradiation using FT-IR, FESEM, XRD, TG/DTA, DSC, and electrochemical methods. The FT-IR analysis confirmed that the EB effect on the chemical interaction by the breaking of chemical bonds and formation of bonding. The SEM morphology images shows that the deep porosity and appearance of interconnect hollow grains at 120kGy. The XRD and DSC studies observed decrease in crystallinity and increasing the amorphous with dose. Optical absorption and band gap studies revealed that they improved with irradiation. Thermal analysis shows the variation of melting temperature and weight loss confirms the enhanced thermal stability due to irradiation. Dielectric parameters, electrical conductivity and electrochemical are enhanced with EB irradiation. The I-V characteristics have been performed at room temperature and shows non-Ohmic behavior with increased current-voltage range upon irradiation. The electrical conductivity calculated using I-V curves after irradiation of about 1.05×10^{-4} S/cm at 120 kGy EB dose was noticed. The observed results are clearly noticed that the PLC nanocomposite material may useful in the rechargeable batteries, storage devices, and high thermal with dose.

Chapter- 6

PVDF-HFP/$LiClO_4$, PVDF-HFP/PEO films, and PANI/$LiClO_4$/CuO polymer composite are prepared successfully using simple methods and exposed to EB irradiation at 40, 80, and 120 kGy doses. The irradiated and EB irradiated samples were characterized using different techniques to know the effect of EB irradiation. The change in the intensity of peaks and wavenumber was confirmed the proper chemical interaction. The surface morphology has changed from rough to smooth surface as well as reduced the size of spherullites and hence turns into more amorphous nature. The optical absorption was increased by shifting the

wavelength towards higher end (redshift) as a results decrease in the optical band gaps was noticed. The electrical conductivity was increased by two to three decimals (10^{-6} to 10^{-3} S/cm) and electrochemical properties significantly increased with irradiation. From the obtained results, it is clear that the improvements in the electrical conductivity properties may confirm this material is prominent candidature for opto-electronic applications.

Scope for future work:

The polymer electrolytes and composites drag more attention in forthcoming days due to the advancement in their physio-chemical properties upon EB irradiation. The modification in the polymeric materials with EB radiation has obtained considerable scope because the energy directly interacts with material may responsible to significant enhancement. Hence, it will very necessary to depth understand charge behavior under the applied field and need to control the radiation processing by optimizing the energy and dose of radiation.

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List of Publications

Papers in Peer Reviewed Journals:

1. A paper titled "Optical Properties and Ionic Conductivity Studies of 8MeV Electron Beam Irradiated Poly (vinylidene fluoride-co- hexafluoropropylene)/ LiClO4 Electrolyte Film for Opto-Electronic Applications" *RSC Advances*, 2018, 8, 15297–15309. (IF 3.108). DOI: 10.1039/c8ra00970h.
   Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Basappa M, Jishnu Dwivedi, V C Petwal, Ganesh S, Devendrappa H*.

2. A paper titled "The Modified Thermal, Dielectric and Electrical Conductivity of PVDF-HFP/$LiClO_4$ Polymer Electrolyte Films by 8 MeV Electron Beam Irradiation". *ACS Omega* 2018, 3, 14188−14200, DOI: 10.1021/acsomega.8b01097.
   Yesappa L, Niranjana M, Ashokkumar S, Vijeth H, Vandana M, Ganesh Sanjeev, Devendrappa H*

3. A paper titled "Increased Porous Morphology and Thermal Degradation of Electron Beam Irradiated PVDF-HFP/$LiClO_4$ Polymer Electrolyte". *Radiation effects and defects in solids*, 173 (3-4), 1-7, 2018.
   DOI: 10.1080/10420150.2018.1486840
   Yesappa L, Niranjana M, Ashokkumar S, Vijeth H, Ganesh Sanjeev, Devendrappa H*.

4. A paper titled "Characterization, Electrical Conductivity and Electrochemical performance of Polyaniline-$LiClO_4$-CuO Nano Composite for Energy Storage Applications". *Polymer-Plastics Technology and Engineering*- 57, 2018,1466175
   DOI: 10.1080/03602559.2018.1466175. (IF 1.232)
   Yesappa L, Niranjana M, Ashokkumar S, Vijeth H, Raghu S, Devendrappa H*

5. A paper titled "Investigation of the Structure, Optical and Electrical Properties of Lithium Perchlorate doped Polyaniline Composite: Aloe Vera used as a Bio-Plasticizer" *Journal of Electronic Materials*. 46(12), 6965-6979, 2017. (IF 1.579).
   DOI: 10.1007/s11664-017-5724-1.
   Yesappa L, Niranjana M, Ashokkumar S, Vijeth H, Chapi S, Raghu S, Devendrappa H.

6. A paper titled "Electron Beam Irradiation Effect on Structure, Morphology and, Optical Properties PVDF HFP/PEO Blend Polymer Films" *Journal of Radioanalytical and Nuclear Chemistry* 2019, 1-6. **DOI:** 10.1007/s10967-019-06466-0. (IF-1.18)
   Yesappa L, Ashokkumar S P, Vijeth H, Basappa M, Ganesh Sanjeev, Devendrappa H*.

7. A paper entitled "Localized Polarons in In-situ Synthesized Polyaniline Nano Composites Improve the Morphology, and Thermal and Electrical Conductivity" *RSC Advances*, 2016, 6, 115074 (IF 3.108).
   M. Niranjana, **L. Yesappa**, S. P. Ashokkumar, H. Vijeth, S. Raghu, H. Devendrappa.

8. A paper entitled “Flexible and high energy density solid-state asymmetric supercapacitor based on polythiophene nanocomposites and charcoal”.
   RSC Advances, 2018, 8, 31414–31426. DOI: 10.1039/c8ra06102e.
   Vijeth H., Ashokkumar S. P., **Yesappa L**., Niranjana M., Vandana M. Devendrappa H.

9. A paper entitled “Camphor Sulfonic Acid Assisted Synthesis of Polythiophene Composite for High Energy Density All-Solid-State Symmetric Supercapacitor”. *Journal of Materials Science: Materials in Electronics*-2019, pp 1-14. DOI: 10.1007/s10854-019-01060-22019.
   Vijeth H; Ashokkumar S P; **Yesappa L**; Niranjana M; Vandana M; H. Devendrappa*.

10. A paper entitled “Structure, morphology and optical studies of Li+ doped polyaniline composite” AIP Conference Proceedings 1832, 040011 (2017); DOI:10.1063/1.4980213.
    L. Yesappa, M. Niranjana, S. P. Ashokkumar, Vijeth, Sharanappa Chapi, S. Raghu, H. Devendrappa

11. A paper entitled “Optical absorption and morphology of biointercalated polyaniline composites” in Advanced Materials Proceedings 2017, 2(7), 436-439. DOI: 10.5185/amp.2017/707
    Yesappa L, Niranjana M, Sharanappa Chapi, Archana K, Raghu S, Devendrappa H.

12. A paper entitled “Morphology, Optical and Ionic Conductivity Studies of Electron Beam Irradiated Polymer Electrolyte Film” AIP Conference Proceedings 1942, 110003 (2018); DOI: 10.1063/1.5028986.
    Yesappa L, Ashokkumar SP, Vijeth H, Niranjana M, Vandana M, Ganesh S, Devendrappa.

13. A paper entitled “Electron beam irradiated polyaniline/liclo4 composite: structure, morphology studies” Proceedings of Int. Conference RAMSB-2018**,** Page 396-398. **[**ISBN 978-93-5291-953-6**].**
    Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Vandana M ,Ganesh Sanjeev, Devendrappa H.

14. A paper entitled “Electron Beam Irradiated Polymer Electrolyte Film: Morphology, Dielectric and AC Conductivity Studies” AIP Conference Proceedings 1953, 050006 (2018); DOI: 10.1063/1.5032661.
    L. Yesappa, M. Niranjana, S. P. Ashokkumar, H. Vijeth, S. Ganesh, and H. Devendrappa.

15. A paper entitled “Structure, dielectric, thermal and I-V studies of electron beam irradiated PVDF-HFP/LiClO4 electrolyte film” AIP Conference Proceedings 1953, 050059 (2018); DOI: 10.1063/1.5032714.
    L. Yesappa, M. Niranjana, S. P. Ashokkumar, H. Vijeth, M. Basappa, S. Ganesh, and H. Devendrappa.

16. A paper entitled "Electron Beam irradiation effect on Structure, Morphology and, Optical Properties PVDF HFP/PEO Blend polymer electrolyte films" in Matter: Int. J. Scie and Tech Conference Proceedings 2018.
    L. Yesappa, M. Niranjana, S. P. Ashokkumar, H. Vijeth, M. Vandana, M. Basappa, Jishnu Dwivedi, V. C. Petwal, G. Sanjeev and H. Devendrappa.

17. A paper entitled "Synthesis, Characterization and Absorption Study of Aloe Vera doped Polyaniline Bio-Composite" Materials Today: Proceedings 5 (2018) 21076–21081.
    Yesappa L, Niranjana M, Ashokkumar SP, Vijeth H, Sharanappa C, Raghu S, Devendrappa.

Papers presented in International/national Conferences:

1. Participated and presented a paper on "Optical Absorption and Morphology of Bio-Intercalated Polyaniline Composite" in International Conference on Materials Science & Technology (ICMTECH-2016) held at Conference Center, University of Delhi, Delhi-110007, India on 01-04 March, 2016.
   Yesappa L, Niranjana M, Sharanappa Chapi, Archana K, Raghu S, Devendrappa H.

2. Participated and presented a paper on "Synthesis, Characterization and Absorption Study of Aloe Vera doped Polyaniline Bio-composite" in International Conference on Smart Engineering Materials (ICSEM-2016) held at R V College of Engineering, Bengaluru - 560 059 during 20-22 October 2016.
   Yesappa L, Vijeth H, Niranjana M, Sharanappa C, Raghu S, Ashokkumar S, Devendrappa.

3. Participated and presented a paper on "Structure, Morphology and Optical Bandgap studies of CuO nano particles added Li/PANI nanocomposite" in DAE-BRNS 6th Interdisciplinary Symposium on Materials Chemistry (ISMC-2016) held at Chemistry Division Bhabha Atomic Research Centre Mumbai-INDIA on 6-10 Dec 2016.
   Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Raghu S and Devendrappa H.

4. Participated and presented a paper on "Structure, Morphology and Optical Studies of Li^+ doped Polyaniline Composite" in 61th DAE Solid State Physics Symposium (DAE SSPS 2016) held at KIIT University, Bhubaneswar- Odisha on 26-30 Dec 2016.
   Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Sharanappa C, Raghu S, Devendrappa H.

5. Participated and presented a paper on "Synthesis, Characterization, Thermal and Temperature dependent Conductivity Studies of Lithium doped Polyaniline Composite" in 4th International Conference on Nanoscience and Nanotechnology (ICONN-2017) held at SRM University, Chennai-Tamilnadu during 9-11 Aug 2017.
   Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Devendrappa H.

6. Participated in a National Conference on "Nanomaterials for biomedical applications (NBA-2017) on 16th March 2017" at Yenepoya University, Mangalore**.**
   Yesappa L, Ashokkumar S P, Niranjana M, Vijeth H, Devendrappa H**.**

7. Participated in a National Conference on "Particle Accelerators in Interdisciplinary Research (PAIR)" held at Department of physics,
   Mangalore University, Mangalagangotri during 11-13th, April 2017.
   Yesappa L, Ashokkumar S P, Niranjana M, Vijeth H, Devendrappa H**.**

8. A National Conference on "Reaching the unreached through science and technology: Recent advances in physics, chemistry, mathematical and biological sciences for energy, health and environment" hosted by Indian Science Congress Association held at Mangala Auditorium, Mangalore University**,** Mangalagangotri-574199 during 8-9th, 2017.
   Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Devendrappa H**.**

9. Participated and presented a paper on "Increased Porous Morphology and Thermal Degradation of Electron Beam Irradiated PVDF-HFP/$LiClO_4$ Polymer Electrolyte" in International Conference on 'Accelerators in Materials and Medical Sciences' 2017 (ICAMMS-2017) held at Amity University, Dubai Campus, Dubai during 5-7 Oct 2017.
   Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Ganesh S, Devendrappa H.

10. Participated and presented a paper on "Morphology and Ionic Conductivity Studies of PVDF HFP/LiClO4 Electrolyte Film Before and After Electron Beam Irradiation" in International Conference on International Conference on Advances in Polymer Science & Technology (APA-2017) held at Radisson Blu Hotel, New Delhi, during 23-25 Nov 2017.
    Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Devendrappa H.

11. Participated and presented orally on "Structural and Optical Property Studies in 8 MeV Electron Beam Irradiated PVDF HFP Doped with LiClO4 Electrolyte Film" in International Conference on International Conference on Advances in Polymer Science & Technology (APA-2017) held at Radisson Blu Hotel, New Delhi, during 23-25 November 2017.
    Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Devendrappa H.

12. Participated and presented a paper on "Electron Beam Irradiated Polymer Electrolyte Film: Morphology, Dielectric and AC Conductivity Studies" in 2nd International Conference on Condensed Matter & Applied Physics (ICC-2017) held at Govt. Engineering College, Bikaner-Rajasthan during 24-25 November 2017.
    Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Ganesh S, Devendrappa H.

13. Participated and presented a paper on "Structure, Dielectric, Thermal and I-V Studies of Electron Beam Irradiated PVDF-HFP/LiClO4 electrolyte film" in 2nd International Conference on Condensed Matter & Applied Physics (ICC-2017) held at Govt. Engineering College, Bikaner-Rajasthan during 24-25 November 2017.
    Yesappa L, Niranjana M, Ashokkumar SP, Vijeth H, Basappa M, Ganesh S, Devendrappa.
14. Participated and presented a paper on "Morphology, Optical and Ionic Conductivity Studies of Electron Beam Irradiated Polymer Electrolyte Film" in 62nd DAE Solid State Physics Symposium (DAE SSPS 2017) held at BARC, DAE Convention Centre, Anushaktinagar, Mumbai, Maharashtra on 26-30 Dec 2017.
    Yesappa L, Niranjana M, Ashokkumar S P, Vijeth H, Ganesh S. Devendrappa H.

15. Participated and presented a paper on "Electron beam irradiated polyaniline/liclo4 composite: structure, morphology studies" in International Conference on Recent Advanced Materials Science and Biophysics (RAMSB-2018) held at Department of Physics, Mangalore University Mangalore, Karnataka during 23-25 January 2018.
    Yesappa L, Niranjana M, Ashokkumar SP, Vijeth H, Vandana M ,Ganesh S, Devendrappa.

16. Participated and presented a paper on "ATR (Attenuated Total Reflectance) FT-IR Spectroscopy for trace evidence in forensic science" in National Conference on "Instrumental Methods of Analysis-2018" held at Jagadguru Tontadarya College Gadag-Betageri–582 101, Karnataka during 29 September 2018.
    Yesappa L, Ashokkumar SP, Vijeth H, Devendrappa H.

17. Participated and presented a paper on "Electron Beam Irradiation Effect on Structure, Morphology and Optical Properties of PVDF-HFP/PEO Polymer blend electrolytes" in 4th International Conference on Application of RadiotraCers and Energetic Beams in Sciences (ARCEBS-2018) held at Ffort Raichak, Kolkata during 11-17 November 2018 organized by Saha Institute of Nuclear Physics (SINP) Kolkata**.**
    Yesappa L, Ashokkumar SP, Vijeth H, Vandana M, Basappa M, Niranjana M, Ganesh S, Devendrappa H.

Seminar/ Work shop attended /Co-Curricular activities

1. Participated in the National Seminar & Workshop on Function Nanomaterials for Energy, Environment and Health organized by Mangalore University, Mangalagangotri on 21st and 22nd March 2016.
2. Participated in the National workshop on Emerging Targets and Biomarkers in Cancer Therapy National Workshop on 16-18 May, 2016 at Mangalore University.
3. Participated in the National Seminar on "Inter-disciplinary Research Challenges and Opportunities" held at Mangalore University, Mangalagangothri on October 18, 2016.
4. Participated in the Per-Conference TUTORIALS of the International conference on International conference on smart engineering materials organized by R.V College of Engineering, Bengaluru during 20-22 october-2016.
5. Participated in the "Emerging Solar PV Technology Applications For Academic**"** Conducted at Mangalore University on 3rd December 2016 at Mangalore University.
6. Participated in a seminar on "Engineering Education & Research Seminar" held at The Gateway Hotel, Mangalore on February 09, 2017.
7. A Global Initiative of Academic Networks (GIAN) programme on "NANOFIBRES AND THEIR APPLICATIONS" held at CARRT Mangalore University Mangalore from 27th Feb. to 6th March 2017.

8. Participated in an international school on “International School on Ion beam in Energy Materials” on 12-18 July, 2018 at Inter University Accelerator Centre (IUAC), New Delhi India.
9. A Global Initiative of Academic Networks (GIAN) programme on “Nanostructure based wide band gap semiconductors for sensor applications” held at Department of Physics, Mangalore University Mangalore from 11^{th} -17^{th} October 2018.
10. Participated in the National Seminar on “Recent Advances in Condensed Matter Physics (NS-RAC)” held at Department of Physics, Gulbarga University Gulbarga during March 26-27, 2019.

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